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Determination of Piston and Cylinder Head Temperature Distribution in a 4-Cylinder Gasoline Engine at Actual Process

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Abstract: - Piston and cylinder head temperature has considerable influence on efficiency, emission, and performance of the SI (Spark Ignition) engine. Purpose of this investigation is measurement of piston transient temperature at several points on the piston and cylinder head, from cold start to steady condition and comparison with results of finite element analysis. From analytical analysis of piston velocity and acceleration forces on the thermocouple wires, due to piston and oil effects were estimated. A flexible compensation wire was employed, and in order to prevent wire entanglement, a suitable pathway was designed. Transient temperatures were measured at ten points on the piston and at five points on the cylinder head. A specially designed low pass electronic filter was used to reduce the spark plug interference and noise. Results show variation of temperature at various points on the piston and cylinder head with time and engine speed.

Key-Words: - Spark Ignition Engine, Piston, Cylinder Head, Measurement, Temperature, Actual process, Experiment

1. Introduction

Piston temperature has an important influence on ignition process of engine, ignition time delay, necessary octane number, and fluid velocity inside the cylinder. Fluid velocity effects considerably on mixing of air and fuel, rate of burning, thermal efficiency, and production of pollutants. Thermal conductivity coefficients, thermal expansion, elasticity module, shear module and other coefficients change with temperature. Therefore, accurate piston temperature distribution is required for piston optimum design, fatigue analysis, and for studding of the development and propagations of crack in piston and evolution of corrosion.

1.1 Previous Research

References [1-6] are the first research efforts for piston temperature measurement by installing thermocouple at several points in different engine pistons. In reference [7] by installing thermocouples 36 points on piston and 12 points on cylinder, authors measured, the piston temperature distribution of air cooled two stroke gasoline engine for different engine speeds, loads, spark time, air-fuel ratio, and cooling air temperature. In such a paper, it was shown that at 2800 rpm, the maximum temperature in center of piston crown was 347°C. By changing the engine speed from 2285 rpm to 2805, the piston crown center temperature increased from 295°C to 347°C. In reference [8] authors measured the piston temperature and by designing of hole on piston wall, they reduced maximum temperature from 260°C to 210°C. According the temperature distribution, surface heat transfer coefficients and heat flux at several points in piston were determined. In reference [9], the author measured the variation of piston temperature in a single cylinder diesel engine with torque and engine speed. Results showed that heat transfer rate increased with increasing engine speed and torque caused by increasing heat release. In addition, they determined that the maximum temperature on piston at maximum power state was 360°C and at maximum torque was about 330°C. In such a paper, it was shown at no-load state, from 2000 rpm to 2200 rpm, maximum temperature of piston changed from 132°C to 181°C and heat transfer coefficient changed from 118 w/(m^2.k) to 347 w/(m^2.k). Also at 1000 rpm, with variation of engine torque from no-load state to 40 N.m, maximum temperature changed from 185°C to 311°C. The reason was increasing average gas temperature from 624 to 1012 Kelvin. In reference [10] piston temperature distribution by finite element method and experimentally was determined.

2. Measuring Method

2.1 Experimental Equipment

1- Engine 2000 cc (Table1.)
2- Thermocouple of type T (copper-constantan)
3- Voltmeter and Ohmmeter
4- Data logger
5- Stroboscope
6-Oscilloscope
7- Tune up system
8- Dynamometer

Table 1: Engine specification

Cylinder No	4
Fuel System	Carburetor
Cooling system	Water
Bore	87.4 mm
Stroke	83.2 mm
Compression ratio	8.4
Displacement volume	2000 cc
Connecting rod length	143.8 mm
Intake valve diameter	32 mm
Intake valve lift	9.7 mm
Intake Valve Open	44° BTDC
Intake Valve Close	82° ABDC
Exhaust valve diameter	24 mm
Exhaust valve lift	9.6 mm
Exhaust Valve Open	64° BBDC
Exhaust Valve Close	18° ATDC
Spark advanced	20° BTDC
Equivalence ratio	1.0

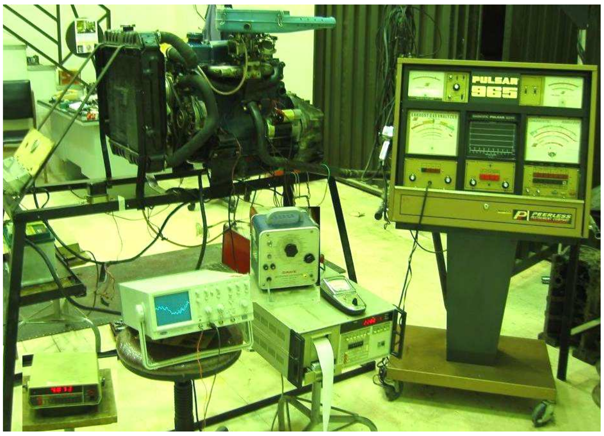

Fig. 1 : A View of engine laboratory and experimental equipment

2.2 Thermocouple selection

A thermocouple contains two different metals. Because of the temperature difference between contact points of two wires, it measures the induced voltage. Thermocouple circuit is shown in Figure 2.

In Figure 2.A a thermocouple is connected to a voltmeter directly, so induced voltage is an indication of temperature difference between T_1 and T_0, However, in Figure 2.B, a thermocouple is connected to compensation wires and then to a voltmeter, so induced voltage is indication of temperature difference between T_2 and T_1 [11,12].

The thermocouple of type T was very flexible and thin, therefore in this test because of the less strength of the thermocouple wires, we use second method. For measuring transient temperature of matter with thermocouple, it should be noted that all thermocouples have delay time to respond to temperature variations. If the heat conduction capability of the thermocouple metal is more and its heat resistance is less, the response time becomes less. Air gap between thermocouple and the position of installation can increase time response, because air or gas is a heat insulator. The junction size and surface roughness has an effect on the time response [13]. Piston is moving by the average velocity of 12 (m/s) inside the cylinder, so the wires should have enough strength and flexibility according to movement of piston and do not fail due to fatigue and should have an appropriate cover to resist against temperature. So according to the test conditions, we use the thermocouple type T that contains cupper metal (positive polarity) and cupper-nickel alloy, constantan, (negative polarity). This thermocouple has the capability to measure temperature between 0 to 370°C, and has 0.4 percent or 1-degree error. Its time response is 1 to 2 second [14]. Through investigations, it had been shown, during less time, less changes in the piston temperature occurred, so it was appropriate case.

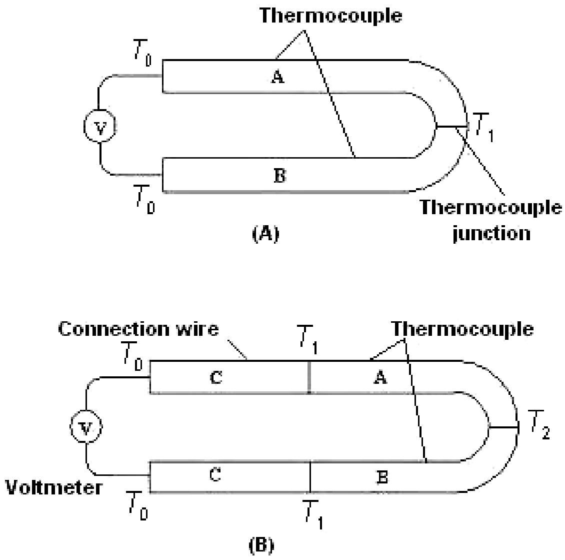

Fig.2. Thermocouple circuit, (A) with out connection wire (B) with connection wire

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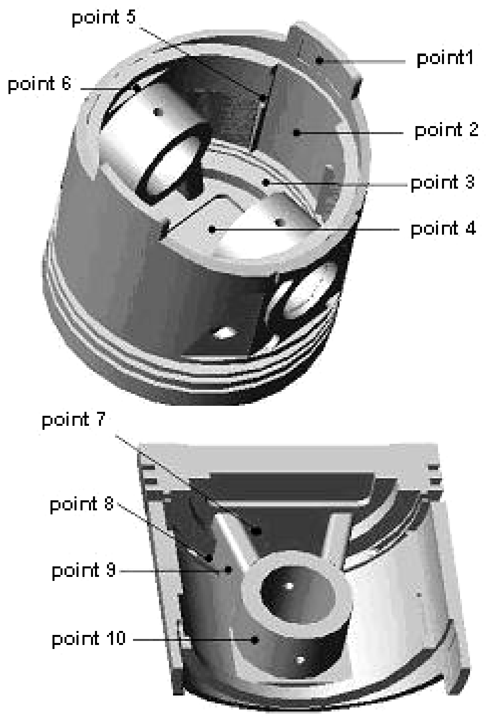

Fig.3. Position of the installed thermocouples on the piston

2.3 Position of thermocouples installing

The surface of piston crown is warmer than the other parts of it and this amount become maximum at the center point, so it is the important point to install a thermocouple. A great amount of heat is transferring by the rings, especially the upper ring. If there was no resistance of contact between rings and cylinder walls, at any points, the temperature of contact points should be equal, but because of the contact resistance, these two temperatures are not equal. Therefore, for determining the real heat transfer coefficient between ring's grooves, another point for installation is ring's groove(point3).

Coefficient of convection heat transfer at different points under piston is deferent because it is located to ejection of oil and there is no perfect model for it, so for determining real heat transfer coefficient, at some points in under the piston, some thermocouples had been installed [15]. Figure 3 shows the exact position of the installed thermocouples.

By producing of hole, less than thermocouple thickness at the position, for reduction of air gap and reduction of time response, thermocouple was installed by pressure at the position, and for avoiding of its movement; its surface was filled by a very thin film of glue. But, the thickness of glue may create an additional resistance, so before installing piston in engine, it was checked by some experiments and the errors of thermocouples in experiment were measured.

2.4 Experimental Method

All measurments were done without installing dinamometer on engine, from cold start to steady condition. Initial temperature of piston and other parts of motor, before starting was the laboratory condition temperature (28.5 °C). Fundamental problem in measuring piston temperature is the signal sending from termocouples to outside of engine. In the previous research, experimental one-cylinder engine that had enough space for instaling likage mechanism for guiding the thermocouple wires, had been used. But at the present test, for exact resultes we used the principle sample of 4-cylinder engine for test. According the previous tests, after 8 to 12 minutes, the engine reached temperature steady condition, so for measuring the temperature variation in piston, wires should survived at least 15 minutes. Thermocouple wires have not enough strength because of being single-wire, so after installing thermocouples on piston and fixing them to connecting rod, we used compensation wires from the middle of connecting rod. But according to Figure 1.B because of using connection wire, induced voltage, was indication temperature difference between T_2 & T_1 so, for measuring the T_1 , we installed another tremocouple in the connection positiion of wires and termocouples. The connection wire should have enough strength in the rang of 650 rpm to 1000 rpm, and should not fail according fatigue during operation, and should have resistance against the vibrations of cranksheft, also should have the cabability to tolerate piston acceleration (Equation 1) and shear stress induced by moving in oil [16].

$$a = \frac{S}{2}\omega^2\left(\cos\theta + \frac{1}{2n}\cos 2\theta\right) \qquad n = \frac{L}{S} \qquad \left(m/s^2\right) \quad (1)$$

S is the piston stroke, L is length of connecting rod, ω is angular velocity and θ is crankshaft angle, according to the Table 1 at 1000 rpm, the maximum acceleration of piston is 588 (m/s^2), the wires should tolerate the inertial force of this acceleration. In addition, the wires should not contact to crankshaft. Because of short space, using of wire with smaller diameter was important. Therefore, by carry out more than 24 tests and using different wires, the desired wires were selected. The distance between connecting rod and case is very small, so the angular force caused wires were ejected and analyzed. Therefore, after connecting the wires to thermocouples and connecting rod by producing hole on the connecting rod and beside the bearing, wires was placed inside it and filled by glue. In order to prevent wires entanglement around the crank angle, a suitable pass way was designed (Figure 4).

Figure 4. A suitable pass way for preventing wire entanglement around the crank angle

In the early tests, it was revealed the waves and noise caused by spark effected to the test data and caused data vibrations (Figure 6), so by installing a Oscilloscope on engine, the shape and frequency of these waves were observed. Because of these frequencies were much higher than the thermocouple frequency (Maximum 5 Hz), By designing a low pass electric filter (Figure 5) and installing before registering place of data, without changing the produced voltage, these frequencies caused by spark plug, were eliminated.

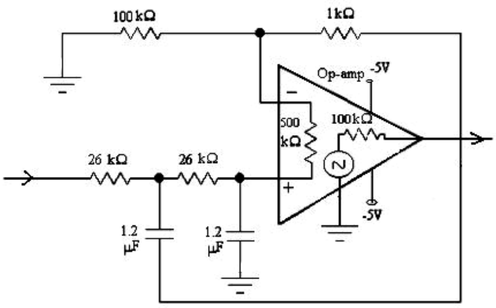

Figure 5. A designed low pass electronic filter,

Since the selected thermocouple is type T, by using Equation 2, the induced voltage converted to temperature and the diagrams of variation of temperatures with time and engine speed at different points were plotted (Figures 7 to 12).

$$T = a_0 + a_1V + a_2V^2 + a_3V^3 + a_4V^4 + a_5V^5 + a_6V^6 + a_7V^7 \qquad (2)$$

T is centigrade degree and V is voltage (volt) [11].

$a_0 = 0.100860910$ $\qquad a_4 = -9247486589$

$a_1 = 25727.94369$ $\qquad a_5 = 6.97688 \times 10^{11}$

$a_2 = -767345.8295$ $\qquad a_6 = -2.66192 \times 10^{13}$

$a_3 = 78025595.81$ $\qquad a_7 = 3.94078 \times 10^{14}$

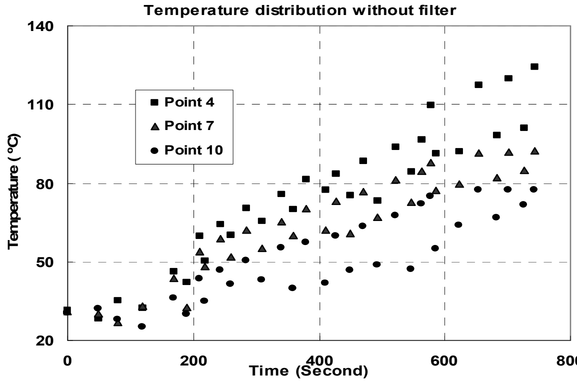

Fig.6 : Measuring of piston temperature without using the filter

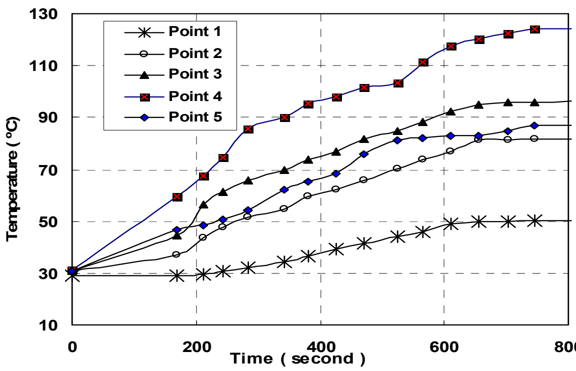

Fig.7 : Variation of piston temperature in different points of piston at 1000 rpm and no-load state

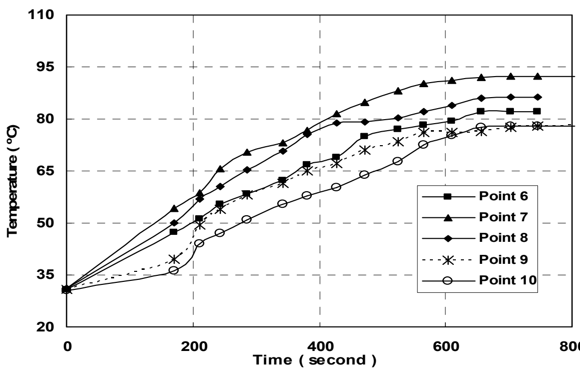

Fig.8 : Variation of piston temperature in different points of piston at 1000 rpm and no-load state

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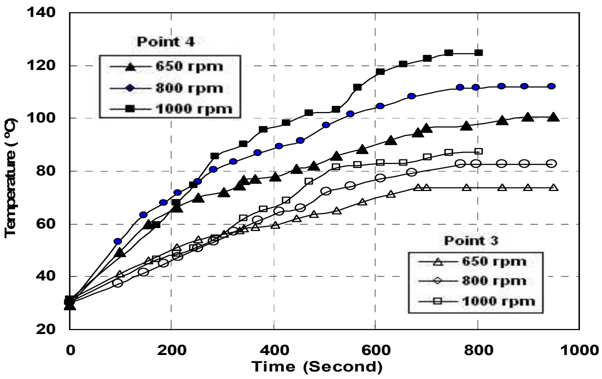

Fig 9 : Variation of piston temperature with time and engine speed at no-load state

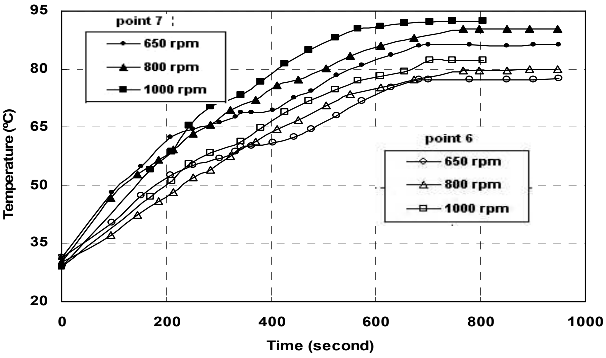

Fig.10 : Variation of piston temperature with time and engine speed at no-load state

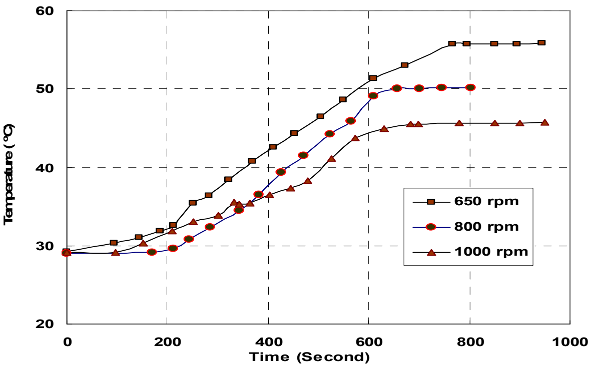

Fig.11 : Variation of oil Temperature with time and speed at no-load state

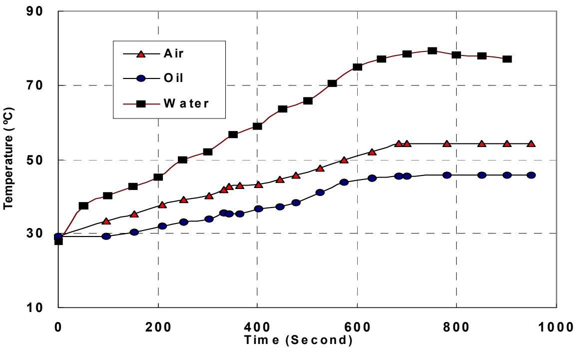

Fig.12 : Variation of crank case air, oil and water temperature with time at no-load.

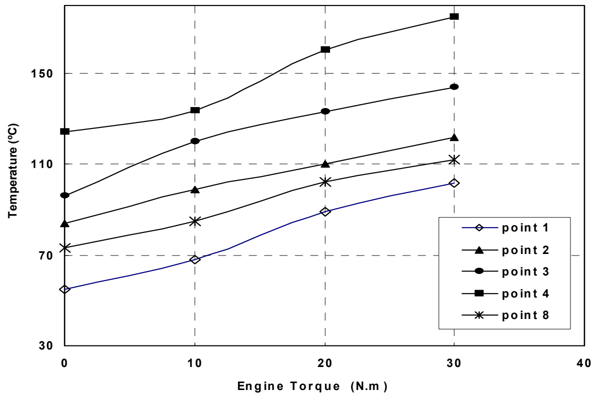

Fig13 : Variation of piston temperature in different position with engine torque at 1000 rpm

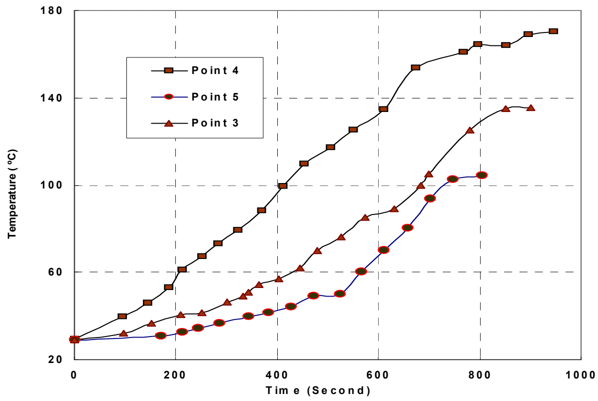

Fig14 : Variation of piston temperature in different points of piston at 1000 rpm and 30 N.m

2.4. Position of Installed Thermocouple on Cylinder Head

By installing thermocouple at five points on cylinder head, variation of cylinder head temperature at 1000 rpm and no-load state was determined (Figure 15,16)

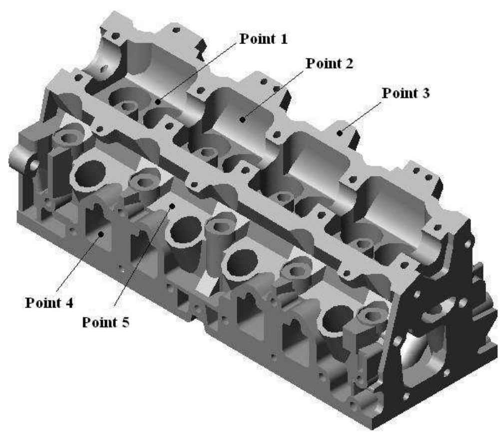

Figure 15. Position of the installed thermocouples on the cylinder head

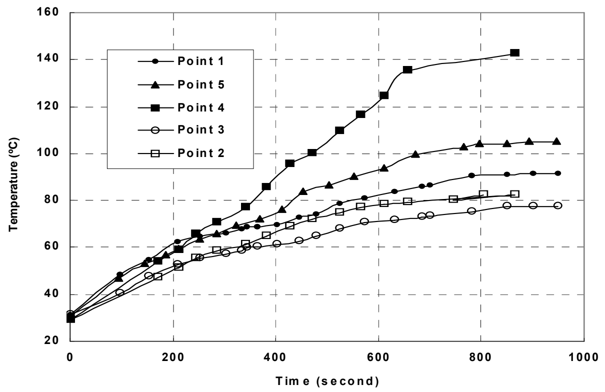

Fig 16 : Variation of cylinder head temperature in different points at 1000 rpm and no-load state

5. Conclusion and Discussion

- From the diagrams (Figures 7 & 8), we can observe at 1000 rpm, the maximum temperature in the center of piston crown (point 4) is 121°C and in the first rings groove is 97°C. In the reference [3] for diesel engine, at no-load state, with variation of engine speed from 700 rpm to 2200 rpm, maximum temperature of piston changed from 132°c to 181°c.
- The test was done at low engine speeds (650, 800, 1000 rpm); it was revealed that after 500 to 800 seconds, all the points reached steady state temperature (Figure 9 to 11).
- The temperature in the center of piston had maximum value, and in the first ring's groove had the highest amount after piston's center. Decreasing rapidly showed that rings have an important influence in cooling (Figure 7).
- By increasing the engine speed, the temperature of oil reduced, at no-load stat, because the angular velocity of fan increased and the heat transfer coefficient of air increased (Figure 11).
- By increasing the engine speed from 650 rpm to 1000 rpm and engine torque from no-load state to 30 N.m, the temperature of different points on piston and cylinder head increased and the rate of increasing temperature raised up (Figure 9,10, 13, 14), because the heat transfer coefficient of gas was increasing with engine speed from 85.2 to $185.4\,w/(m^2.k)$ and gas mean temperature increasing from 561 K to 623 K.
- According to the results of the test, by a finite element software and piston simulation, we can determine exact heat transfer coefficients at different surfaces, especially on the piston rings.
- With accurate piston temperature distribution, piston optimum design and studding of the development and propagations of crack in piston and evolution of corrosion could be done.

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